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## APPLICABILITY OF ERTS-1 TO MONTANA GEOLOGY

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16. Abstract <b>Geologic maps of four test sites were compiled at 1/250,000. Band 7 prints enlarged to 1/500,000 scale are the best for our purposes, and negative prints provide a valuable supplement. Stereoscopic U-2 test site photographs are indispensable for relating map data to ERTS imagery; metric camera color-infrared transparencies are particularly helpful, as are black and white prints made from them. A mosaic of 9" NDPF prints for western Montana was used successfully for lineament map construction, although such prints are not ideal. More than 100 mapped lineaments represent most of the major faults of the area and a large number of suspected faults, including many of northeast trend. Under ideal conditions dip slopes may be recognized, laccoliths outlined, and axial traces drawn for narrow, plunging folds. Use of ERTS imagery will greatly facilitate construction of a needed tectonic map of Montana. From ERTS imagery alone, it was possible to identify upturned undivided Paleozoic and Mesozoic strata and to map the boundaries of mountain glaciation, intermontane basins, a volcanic field, and an area of granitic rocks. It was also possible to outline clay pans associated with bentonite. However, widespread recognition of gross rock types will be difficult.</b>					
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## PREFACE

The primary objective of the investigation is to develop tectonic and paleogeologic mapping methods using ERTS imagery for Montana. Work during the period included compilation of ground truth maps, evaluation of image analysis methods for ERTS imagery and U-2 photographs, preparation of an ERTS mosaic and construction of a lineament map from it, annotation of folds and domes, and efforts to recognize and delineate certain gross rock types.

It is concluded that ERTS imagery is very practical for tectonic mapping and analysis. ERTS-derived lineaments represent most of the major faults of western Montana and a large number of lines to be checked as possible faults. A set of northeast-trending lineaments is prominent. Under ideal conditions narrow, plunging folds and small laccolithic domes are easily delineated.

A number of gross rock types were accurately outlined from ERTS imagery, but positive identification of major rock types from imagery alone is very limited at this stage. The imagery will speed compilation of a needed tectonic map of Montana and when calibrated from ground truth will provide corrected contact locations useful for revision of the state geologic map.

Our work would be facilitated if the NDPF could provide negatives for enlarging which are less dense and prints for late fall which are normalized to the average tone of summer prints.

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## INTRODUCTION

This report covers compilation of ground truth, evaluation of image analysis methods, and the results of pilot tectonic and photogeologic mapping studies for Montana based on ERTS-1 imagery supplemented by U-2 test site photography. Types of ERTS imagery utilized were 9" NDPF prints in single and mosaic form, 18" (1/500,000 scale) enlargements made by us from copy negatives, 9" diapositives studied on the Zoom Transfer Scope, and 70mm diapositives projected on the optical color enhancer. Types of U-2 photographs studied included multispectral 70mm diapositives, 70mm red band contact print mosaics, metric camera color-infrared transparencies, and derived 9" black and white prints.

Mapping studies emphasize targets of opportunity in western and central Montana. Investigations included lineament mapping, annotation of folds and laccoliths, and delineation of intermontane basins, volcanics, and granite. An area of known bentonite deposits was also studied.

## MAIN TEXT

### Data Utilization Techniques

Prior to receipt of imagery most of the effort under this investigation involved gathering ground truth data for Test Sites 354 A & C, B, D, and F (see Appendix A). Following a literature search geologic maps of the sites and some adjoining areas were compiled from existing maps at scales of 1/250,000 and larger. The ground truth maps were drawn on United States 1/250,000 Scale Series topographic base sheets and colored to show the gross rock units listed in Table I.

In connection with the investigations reported separately below, much time was devoted to determining the relative utility of the different forms of ERTS and U-2 imagery and to evaluating analysis methods. MSS Band 7 (infrared)\* is best for most of our purposes because it most clearly shows shadow detail needed for interpretation of landforms in

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\* NDPF band code numbers will be used throughout this report.

Table 1. Ground Truth Map Rock Units

Surficial deposits (differentiated where possible)  
Tertiary basin fill  
Sandy rocks, including quartzite  
Shaly rocks, including argillite  
Carbonate rocks, including dolomite and marble  
Granitic rocks, including granodiorite  
Intermediate volcanic and acidic volcanic rocks  
Basalt, gabbro diorite  
Gneiss  
Pelitic schist  
Calc-silicate rocks and amphibolite

forested areas and in general minimizes contrasts between naturally occurring vegetation types. Nine inch prints were studied both under reflected light and with back-lighting from a light table; the latter method was necessary in order to effectively utilize late fall NDPF prints, which are very dark for our area. ERTS 70mm diapositives were used for lantern slide projection during group discussions, for making negative enlargements, and for color-additive viewing. Compared to 9 and 18 inch paper prints\* the only apparent advantage of these diapositives for interpretation purposes was for cases requiring strong illumination of dark scenes.

A Band 7 mosaic for western Montana was laid over a drainage net traced from the USGS 1:1,000,000 scale state base map using 17 NDPF prints taken in late August. The bulk processed prints matched the base control very well and the mosaic was used for lineament mapping. However, it is regarded as an interim product not suitable for reproduction because of tone mismatch and obvious joint lines. A second mosaic is therefore being prepared, using our own enlargements made on paper which does not have a plastic backing; this will allow both tone matching and less conspicuous joints. Back-coated enlarging paper creates problems at joints and is also difficult to mount with gum arabic.

We have made a number of 18" enlargements using Plus-X 4x5 inch

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\* Throughout this report 9" prints refers to 1:1,000,000 scale enlargements supplied by NDPF; 18" prints refers to 1:500,000 scale enlargements made in our darkroom.

copy negatives of ERTS 70mm diapositives. These enlargements seem ideal for most of our applications. They show detail without need for reading glass magnification, allow annotation of geological detail without undue crowding, and may be compared directly with the 1:500,000 scale Geologic Map of Montana. They are also readily compared to our test site maps using 2x enlargement.

Preliminary use of the Spectral Data Model 64 color additive viewer produced color-infrared and other false-color displays of several western Montana scenes, which were successfully recorded with good fidelity and resolution on 35mm Ektachrome EHB film.

U-2 photography of our Western Montana test sites (Flight 72-125, 26 July 1972) was utilized in several ways. 70mm Vinten camera diapositives were studied on the light table under the zoom stereoscope and found to be useful at magnifications as high as 25x. LogEtronics contact prints of 70mm red band negatives were made into test site mosaics at a nominal scale of 1:439,000. The results were disappointing, and it was decided that a larger scale U-2 mosaic would be more useful (see below). A 7x red band enlargement proved to be very useful for photo-geologic annotation, as did metric camera contact prints and enlargements.

RC-10 metric camera color-infrared photography was utilized in two ways. Nine inch transparencies (scale approximately 1:125,000) were studied on the light table under the zoom stereoscope at useful magnifications as high as 30x. In addition to providing color-infrared signature information these high resolution pictures provide a second, lower level bridge to the ground when compared to the Vinten camera photographs. We also used the metric camera photographs in black and white contact print form and as 3x and 5x enlargements made from a contact-printed negative roll prepared for us by Ames Research Center. The prints provide a basis for drawing annotations of interpretations of the color transparencies made under the zoom stereoscope. They will also be used for test site mosaics.



We have experimented with negative prints at 1:500,000 scale (See Figure 1) and find that they often provide important advantages when used as a supplement to positive prints. They afford a new point of view and, under certain circumstances, provide strong enhancement of image texture, drainage patterns, and landform detail. They also allow direct enlargement from diapositives for which the NDPF negatives are so dark that making positive enlargements is difficult.

A Zoom Transfer Scope received very late in the reporting period has been used on a trial basis for transferring ERTS annotations to a blank base map at larger scale, and for direct comparison of ERTS annotations with larger scale ground truth maps. The instrument allows precise scale adjustment and rapid transfer of data along the swath of mirror scan. When working at higher magnifications, lack of capability to scan up and down the easel requires that both the imagery and the map be moved several times per scene. In trying the instrument for direct photo-interpretation, particularly at higher magnifications, it was found that 9 inch diapositives are better than prints of the same size or 70mm diapositives because they allow higher intensity illumination.

### Tectonic Analysis Feasibility Studies

#### Lineaments

Completion of a 1:1,000,000 scale mosaic for western Montana at the end of October provided the occasion to construct a preliminary coarse-scale lineament map for a large area (See Figure 2), following our proposed long-range goal of developing techniques through lineament annotation for the compilation of a tectonic map of Montana. Detailed lineament study for test sites 354 A-C, and 354B was deferred in favor of the broader investigation because of delay in delivery of a zoom stereoscope needed for interpretation of U-2 photographs.

Lineament annotation was done separately by two interpreters. In one case a clear acetate overlay and permanent, colored overhead projector pens were used; in the other case single-matte-sided polyester

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Figure 1. Negative enlargement of Lewistown area, central Montana. (Band 6, ID# E-1087-17402, 18 October 1972), printed from NDPF 70 mm diapositive. Dip slopes and domal structure are readily apparent. Compare Figure 4.

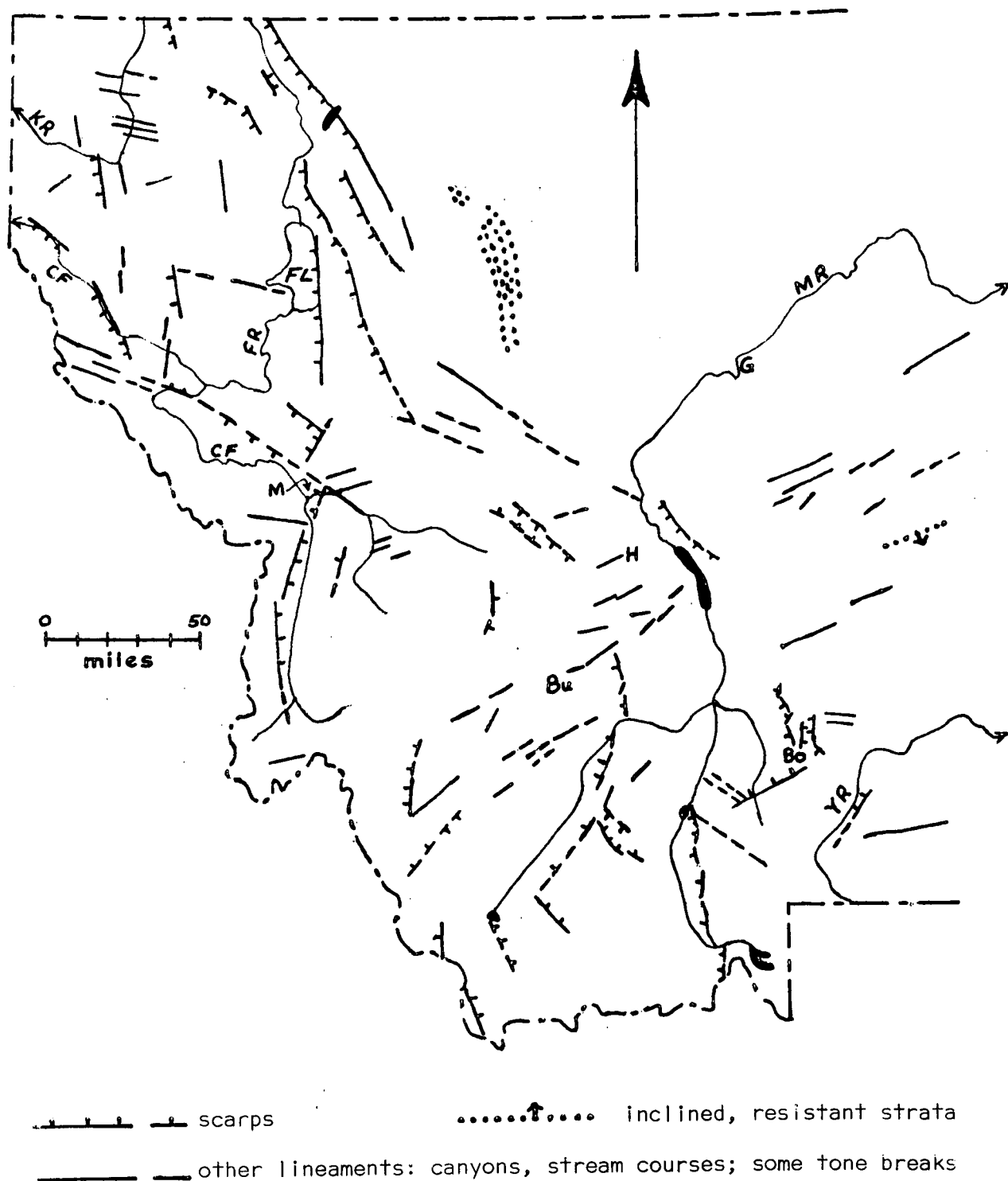


Figure 2. Preliminary ERTS lineament map of western Montana, drawn originally at 1:1,000,000 scale on overlay of Band 7 mosaic for late August, 1972. M - Missoula, Bu - Butte, Bo - Bozeman, H - Helena, G - Great Falls, KR - Kootenai River, CF - Clark Fork of Columbia, FR - Flathead River, FL - Flathead Lake, MR - Missouri River, YR - Yellowstone River. Lineaments dashed where vague.

drafting film and colored pencils were used. Acetate sheeting has the advantage of being transparent. Although the matte-surfaced film had to be annotated with back-lighting from a light table, it allowed erasing for subtraction or relocation of lines. The two maps were compared, minor differences reconciled, and the resulting map was reduced to 1/3 scale using a Kail reflecting projector. Most of the lineaments are fracture-controlled features with strong topographic expression, primarily scarps and straight canyon segments, though some are straight stream courses in lowland areas. Only a few of the most prominent stratigraphically controlled lineaments have been shown, representing strike ridges in the Sawtooth Range structural salient and along the southeast flank of the Little Belt Mountains.

Most of the important normal faults of the area are represented on the lineament map. Major faults of this type are shown as scarps in the area east and north of Flathead Lake. Another group of normal faults readily apparent as lineaments are those marking the boundaries between mountain blocks and Tertiary basins in southwestern Montana. Faults bordering the northeastern and northwestern sides of the Ruby Mountains, the west flank of the Tobacco Root Mountains, and the western side of the Madison, Gallatin, and Bridger Ranges are particularly good examples. These and other mountain front lineaments (fault-line scarps) compare well with faults mapped by Burfeind (1967) on the basis of extensive geophysical work.

Low angle faults such as the Lewis overthrust are not apparent, although higher angle reverse faults might be inferred from the arcuate ridge pattern representing the Sawtooth Range structural salient (75 miles west of Great Falls).

West-northwest trending lineaments belonging in the broad zone of the Montana lineaments are rather weakly expressed and have purposely been given only minimal checking against ground truth maps until a more detailed, larger scale lineament map is constructed. An example of a fault of this trend which is apparent on ERTS imagery but was difficult to map on the ground is the eastern extension of the Shroder Creek fault (LaPoint, 1971), shown as a lineament extending 17 miles west from

Flathead Lake. Ground mapping by LaPoint suggests that this fault has undergone one to two miles of right slip.

Short and medium-length lineaments of northeast trend are prominent southeast of a line connecting Missoula and Great Falls and appear to represent a significant fracture trend. One of these is the very straight southeast-dipping flank of the Little Belt uplift. Another, which marks the valley of the Little Boulder River, was mapped for 19 miles and trends southwest through the strongly mineralized mining district at Butte.

Prominence of northeast lineaments in contrast to weak expression of well known northwest lineaments is apparently a function of illumination direction and confirmation that the lineaments drawn are seen mainly because of their topographic expression.

Only about half of the mapped lineaments are represented on the state geologic map, and limited comparisons with more detailed maps suggest that many of these will merit investigation as possible faults. A case in point is the set of six west-trending lineaments crossing the Kootenai River Canyon (extreme northwest corner of the state). Only the southern two of these lines, all of which represent exceptionally straight tributary canyons, are shown as faults on the 1:125,000 scale geologic map of the area (Johns, 1970). It is interesting to note that two minor earthquakes recorded by the Libby Dam reservoir seismic network in August, 1972, had epicenters along the southernmost lineament (personal communication, Gary W. Crosby, University of Montana).

#### Folds and Domes

The utility of ERTS imagery for fold recognition was checked in a preliminary way for the area between the southern Elkhorn Mountains and the Crazy Mountains, using an 18" Band 7 enlargement (ID# 1034-17461, 26 August 1972). Conditions for imaging fold patterns are ideal because folds in this area occur mainly in differentially eroded Paleozoic and Mesozoic strata, and forest cover is minimal. Fold patterns are expressed

by strike ridges and valleys with local relief of a few hundred feet, and by tonal banding. Topographic expression is the most apparent recognition criterion and the only clue to fold type (from dip slope).

The experiment resulted in the recognition of 11 plunging folds ranging in wave length from one to 10 miles. Four of the folds were correctly identified as anticlines or synclines, five could not be identified from the imagery as to fold type, and one was misidentified as to type. One could not be checked for lack of ground truth, but the other 10 were more accurately located. Photogeologic lines for a fold pair suggest that a significant correction could be made in the outcrop pattern of the state geologic map.

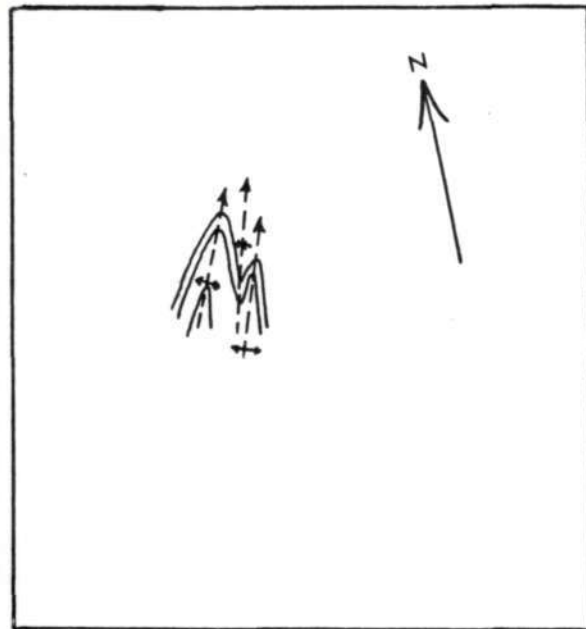
Figure 3 is an example of subtle fold expression of Belt and Paleozoic strata in the southern Elkhorn Mountains showing three axial traces in a distance of 2.5 miles. This example indicates that under ideal conditions plunging folds with wave length as small as one mile may be delineated. It should be pointed out that although axial traces were drawn from the imagery, fold type and plunge direction could not be inferred and had to be obtained from a geologic map; photogeologic lines and map contact pattern matched perfectly.

Delineation of laccolithic domes, broad folds, and dip direction was tried for the Neihart-Lewiston area, which covers part of the broadly anticlinal, east-trending central Montana uplift. During preliminary examination of a negative enlargement shown in part in Figure 1, it was noticed that circular patterns are very apparent in an area of known intrusive doming, and that partially removed roof strata show wrap-around patterns and easily recognized dip slopes in many cases. A simple overlay (Figure 4) was constructed showing inferred domes (based on landforms and drainage patterns) and delineating the Little Belt and Big Snowy uplifts by a photogeologic line drawn at the base of their dip slopes; this line probably represents the approximate horizon of the non-resistant Jurassic Morrison Formation. Certain other pronounced tonal and topographic lines were also drawn.





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Figure 3-1 (left). Band 7, 1:500,000 scale enlargement of the southern Elkhorn Mountains area (ID# E-1034-17461, 26 August 1972). Photogeologic lines in Figure 3-2 (right) represent contacts in Belt and Paleozoic sedimentary rocks. Axial traces were drawn from the imagery; fold identification was taken from ground truth.

The photogeologic line at the horizon of the Morrison (?) Formation matches the state geologic map closely for the bases of the Judith, Moccasin, southern Big Snowy, and southeast Little Belt Mountains, where dips are moderately steep. Where dips are gentler, as on the north flanks of the Big Snowy and Little Belt Mountains the accuracy of delineation is not as good.

The intrusive domes of the area, which range in diameter from three to eight miles, were emplaced at horizons ranging from Cambrian to Cretaceous. For many of the domes, especially those in the Judith and Moccasin Mountains, erosion has exposed the igneous cores. Of 18 suspected domes mapped from ERTS Imagery, most correspond to domes on the state geologic map and three require further checking. Only a few of the domes shown on the geologic map were not noted during image annotation.

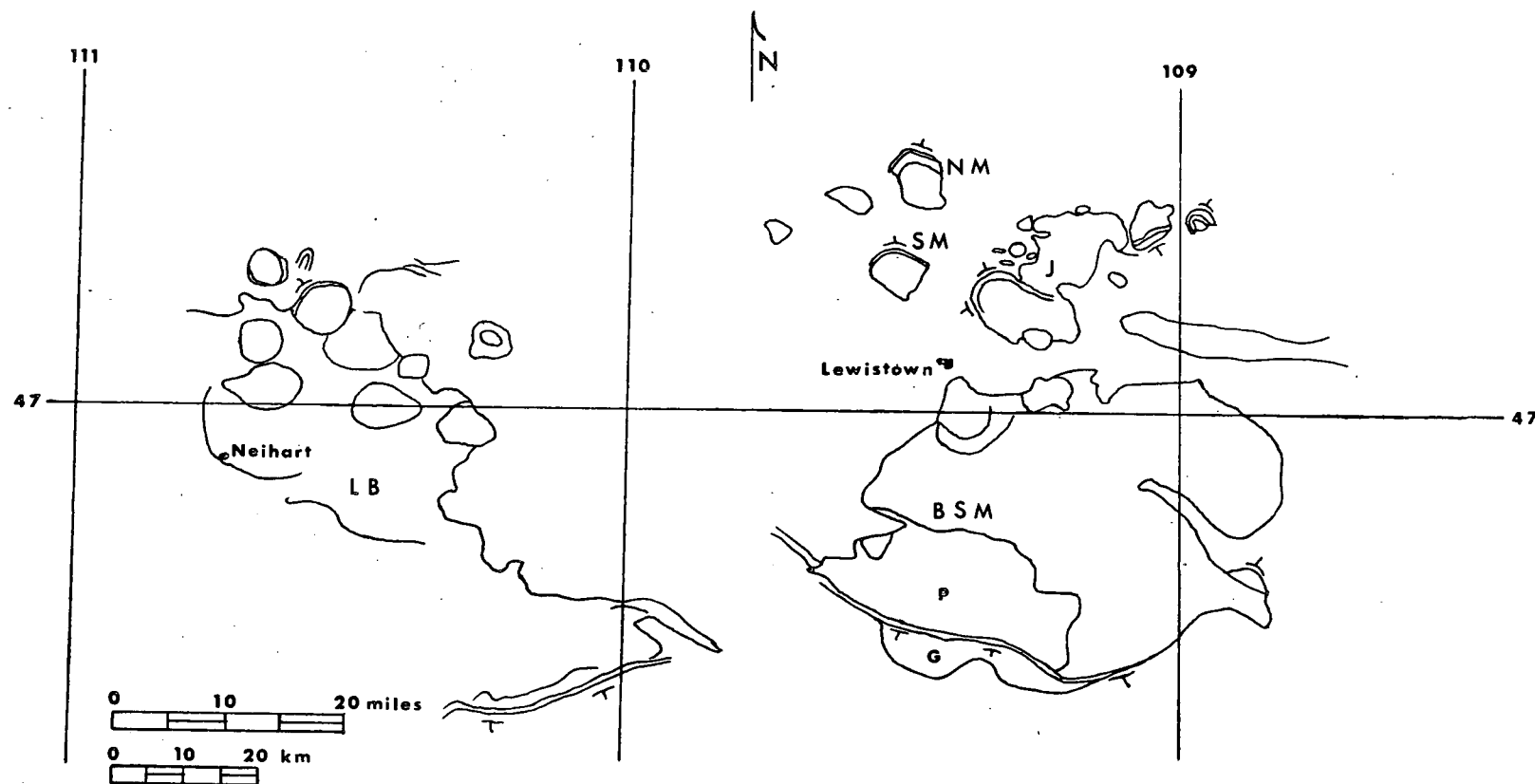


Figure 4. ERTS delineation of intrusive domes and the central Montana uplift in the Neihart - Lewistown area, drawn originally from a larger scale negative enlargement (see Figure 1). J - Judith Mountains, NM - North Moccasin Mountains, SM - South Moccasin Mountains, BSM - Big Snowy Mountains, LB - Little Belt Mountains. Double and single lines around outside of Big Snowy and Little Belt Mountains represents approximate horizon of Jurassic Morrison Formation. P - Paleozoic strata, G - area identified as terrace gravels on state map.



## Photogeologic Mapping Investigations

### Introduction

Glaciated areas in the mountains are rather easily mapped by such geomorphic features as cirques, tarns (black for Band 7), U-shaped valleys and moraines. Flood plains (in the broad sense) are often mappable on the basis of irrigated fields.

With a few exceptions, recognition and delineation of gross lithologic types in western Montana ERTS imagery is proving to be difficult. It seemed advisable to concentrate initially on recognition of several rock types which occur over extensive areas to see if they might be outlined on ERTS imagery and to seek a diagnostic set of recognition characteristics. These rock types included Cenozoic basin fill, undifferentiated Paleozoic strata, undivided Mesozoic strata, certain volcanic fields, and granitic rocks. Successful recognition and delineation has been limited and has relied more on landform, drainage pattern, and image texture than tone signature. Future work will involve more detailed approaches utilizing test site U-2 photography and working from ground truth up to ERTS imagery. Such work will also involve overcoming the problem of the vegetative screen.

### Cenozoic Basin Fill

Areas underlain by Cenozoic fill in the intermontane basins of southwestern Montana may be rapidly and fairly accurately outlined from ERTS imagery on the basis of geomorphic and vegetative characteristics. Most of the boundaries tend to be fault scarps or fault-line scarps which are heavily forested; the basin floors underlain by Tertiary and Quaternary fill are grass and sagebrush covered lowlands. Band 5 imagery is best for mapping the vegetation boundary; Band 7 imagery is best for recognition of the slope boundary on a topographic basis. Basin delineation according to the foregoing criteria results in inclusion of limited areas of pedimented older rocks with the basin fill.

## Upturned Paleozoic and Mesozoic Strata

In areas where Paleozoic and Mesozoic strata have been folded or tilted the dominant carbonate composition of the Paleozoic rocks causes them to be more resistant to erosion than the clastic Mesozoic section. The Paleozoic strata usually stand out as areas of higher, more rugged topography, with a bounding dip slope from which the Mesozoic strata have been stripped away. Undifferentiated Mesozoic strata underlie lower areas characterized by smoother topography and lower relief. Pronounced parallel ridge and valley topography is more characteristic of undivided Paleozoic rocks than of Mesozoic beds. In places ERTS imagery reveals forest covered ridges surrounded by grasslands; these ridges are correlated to the major sandstone formations of the Paleozoic, the Flathead at the base and the Quadrant near the top.

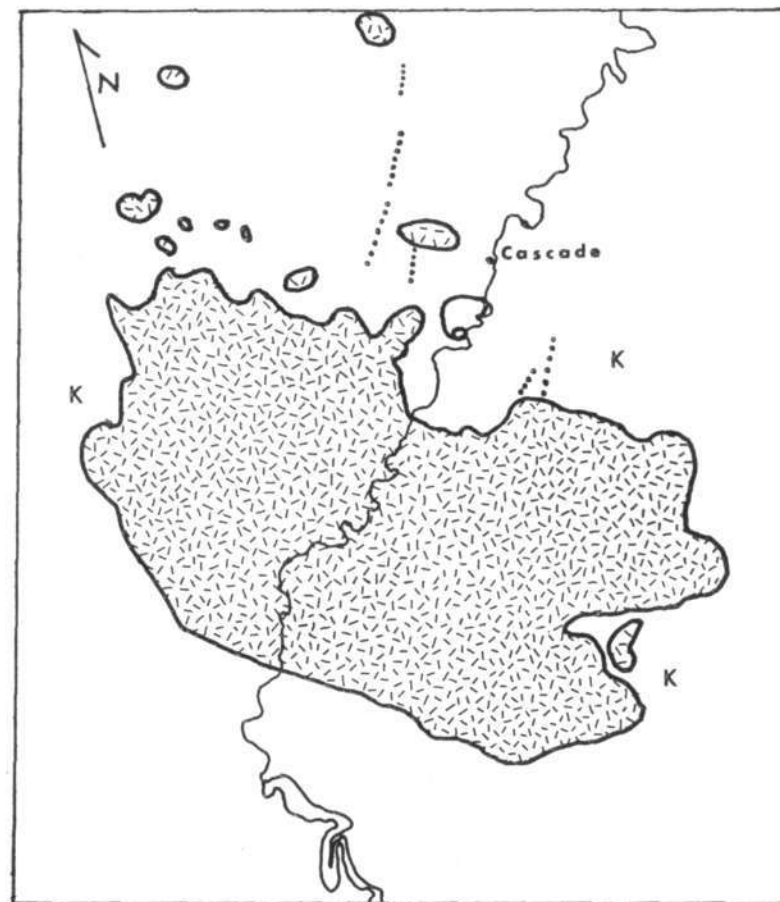
## Volcanic Rocks

The Elkhorn Mountains, Adel Mountain, and Lowland Creek volcanic fields were studied in some detail in ERTS imagery in an effort to develop recognition criteria for volcanics of different composition and age. These were examined in print form at 1:1,000,000 and 1:500,000 scale; for the last named field a negative print was used as a supplement. Study of these volcanics with the aid of the color enhancer has not yet been fully exploited. Our general approach was to study imagery until geologic boundaries of the volcanic fields became subjectively apparent, after which the boundaries were drawn on an overlay and checked against available ground truth information. For the cases where the boundaries withstood the check against ground truth, the imagery was critically re-examined to determine which characteristics were distinctive.

The most success in recognition and delineation of volcanics was achieved for the Adel Mountain volcanic field, which lies on both sides of the Missouri River Canyon between Wolf Creek and Cascade (See Figure 5). These volcanics consist of some 3200 feet of dark-toned rocks ranging in composition from trachybasalt to latite and resting disconformably



0 10 miles 0 10 km



River ——— Contacts ——— Dikes . . . . .

Figure 5-1 (left). Band 7 enlargement of Adel Mountain Volcanic Field and Missouri River Canyon. (ID# 1089-17515, 20 October 1972).

Figure 5-2 (right). Contacts of Adel Mountain Volcanics drawn from Figure 5-1. K - Cretaceous formations. Pattern - volcanics, except for outliers to north, which are laccoliths.

on shaly Cretaceous beds. Dips are gentle to moderate. Eruption probably occurred in latest Cretaceous time, when lava was also intruded outward as dikes to form a number of laccoliths to the northeast. The laccoliths have been unroofed and occur mainly as buttes exposing the igneous rock on the tops and upper edges.

The Adel Mountain volcanic field and its outpost laccoliths are distinguished by dark tone; this tone, which results from a combination of bedrock influence and scrub forest cover, is apparent even where trees are absent. The main field is characterized also by rough topography and medium-textured drainage of irregular pattern, as well as lack of regular internal structure. The larger laccoliths show mesa-like form. Surrounding grass-covered Cretaceous strata are lighter in tone and smoother in image texture.

Comparison of the ERTS-drawn contacts of the volcanic field with those of the Geologic Map of Montana indicate excellent correspondence. Contacts are within a mile of each other over an estimated 80 per cent of the perimeter. A minor peninsula of volcanics at the southeast corner of the field was not mapped from the imagery, and a mistake was made just south of Cascade, where patches of terrace were mapped as a laccolith (shown without pattern in Figure 5-2).

Four lines of northeast trend mapped from the imagery are the expression of thin, steeply-dipping dikes cutting horizontal strata. The two dikes east of the river are prominent ridges. Validity of ERTS mapping of the long dike on the west is complicated by proximity to a road.

Interpretation of the Lowland Creek volcanic field, located in the vicinity of Butte and Anaconda, is much more difficult than for the Adel Mountain field. The Lowland Creek volcanics consist of some 6000 feet of flows and pyroclastics of quartz latite and rhyolite composition erupted during the Eocene, after erosion had exposed rocks of the Boulder batholith on which the volcanics lie. In general, these volcanics appear hummocky and are distinguishable by their relatively open drainage

texture and lack of apparent structural control in drainage pattern (compared to the batholithic rocks). They are quite different in appearance from the younger Tertiary sediments with which they are in contact on the west; these are characterized by a smooth image texture. Parts of the boundaries between the volcanics and the granitic rocks and Tertiary sediments were successfully drawn from ERTS imagery.

The andesitic Elkhorn Mountains Volcanics located mainly on the east flank of the Boulder batholith were erupted during Cretaceous time, almost simultaneously with the emplacement of the batholith. Probably because they are close in composition to the batholithic rocks they presently appear indistinguishable in ERTS imagery.

#### Granitic Rocks

A wide variety of granitic rocks is included in the western Montana area and efforts have been made to develop criteria for their recognition in ERTS imagery. These efforts have been directed toward recognition of granitic rocks directly and toward recognition of them through their structural relationship to surrounding rocks. Most of the effort has been based on visual examination of prints at scales of 1:1,000,000 and 1:500,000, including some negative prints. Intensive efforts to find criteria based upon use of the optical color enhancer were without notable success. These efforts will be resumed when imagery taken during the spring and early summer growing seasons becomes available, to determine whether the lithologies can be distinguished on the basis of the vegetation they support.

The procedure used in print study was the same as that used for volcanic rocks. Most of the effort to develop criteria for recognition of granitic rocks have been directed toward the Boulder batholith and certain associated intrusives. Broadly speaking, the granitic rocks of the Boulder batholith can be distinguished from the surrounding rocks, except for the Elkhorn Mountains Volcanics, but with some difficulty and considerable local uncertainty. The granitic rocks are distinguished

by their rather open drainage texture and a drainage pattern structurally controlled by fracture patterns, markedly non-dendritic. The absence of apparent sedimentary beds is obvious and helpful.

A detailed study of ERTS imagery for the Pioneer Mountains area of southwestern Montana resulted in the construction of an overlay showing the inferred outlines of granitic bodies (Figure 6). Granitic rocks were differentiated on the basis of their non-layered appearance where they are in contact with Paleozoic sediments, and their fine-spaced, non-dendritic drainage pattern where they are in contact with Precambrian low rank metamorphic rocks (Missoula Group). Results were compared with the state geologic map, which was traced onto the overlay. In general the contacts coincide closely, although an area of granitic rock toward the northeast was omitted from the ERTS interpretation. A notable discrepancy occurs in the southwestern part of the range, where image texture strongly suggests that an arm of granite connects a body on the east with one on the west. This inferred connection will be field checked.

Smaller granitic intrusives are difficult to recognize directly but likely to betray their presence through their structural effect on the surrounding rocks. Castle Mountain, a small granitic stock near White Sulphur Springs, is strikingly evident through the fact that it is surrounded by upturned sedimentary beds.

A medium-sized batholith located in the center of the Tobacco Root Mountains and outcropping at high elevation is not apparent on the ERTS imagery to date. Neither are several small batholiths in the Flint Creek Range which also outcrop at high elevation. But a small stock that outcrops at low elevation in the Sapphire Range is readily apparent. It seems likely that there is an elevational control governing the way in which granitic rocks are expressed in ERTS imagery. Probably this is due to the fact that the granites which outcrop at low elevation tend to be much more deeply weathered than those outcropping at high elevation.

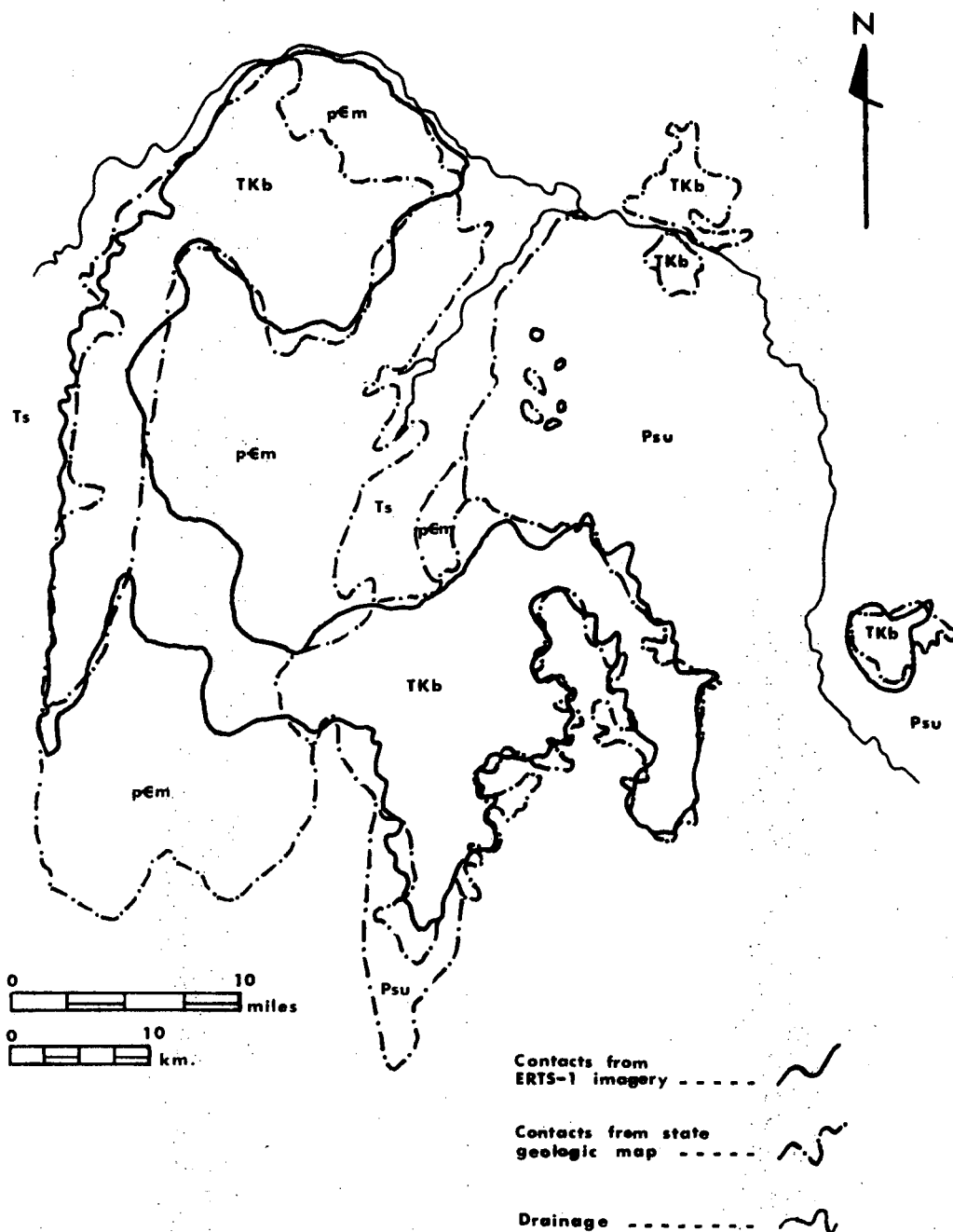


Figure 6. Overlay map for Pioneer Mountains area showing delineation of granitic rocks from ERTS imagery (based on 1:500,000 scale enlargement, Band 7, ID# 1035-17520, 27 August 1972). Identity of the surrounding rocks was taken from the Geologic Map of Montana. pEm - metamorphosed Missoula Group, Psu - Paleozoic sediments undifferentiated, TKb - granitic rocks related to Boulder Batholith, Ts - Tertiary basin fill.

### Economic Mineral Deposits Studies: Bentonite

The possibility of recognizing Bearpaw Shale known to contain bentonite beds of economic potential was investigated for an area on the flanks of the Ingomar anticline, where the ground truth is well known (Berg, 1970). The area is located about 80 miles northeast of Billings. Negative enlargement prints at 1:500,000 scale were made from diapositives of Bands 4, 5, 6, and 7 for a scene imaged on 16 October, 1972 (ID# E-1085-17291). Band 5 was selected as best for annotation purposes. Two overlays were drawn, one delineating highly reflective areas of irregular pattern and the other showing a continuous tonal boundary thought to represent a lithologic contact. The results were compared to a 1/500,000 scale lithologic map and to aerial photographs at a scale of 8" = 1 mile covering most of the bentonite deposits of the area. The three maps, which have been combined in Figure 7, indicate that the suspected photogeologic contact closely matches the sandstone-shale contact which marks the center of the anticlinal dome (Judith River - Bearpaw contact).

Known bentonite exposures in the area are too small to be recognized directly in ERTS imagery, but the irregular reflective patches may be a clue to their occurrence. These areas of high reflectivity are surficial clay pans (mud-filled channels and depressions) developed in this area on the Bearpaw Shale where dips are less than 3 degrees and where bentonite beds are well exposed. Further work may show that areas of high reflectivity can be used for recognition of those areas within the Bearpaw Shale where thicker bentonite beds are exposed.



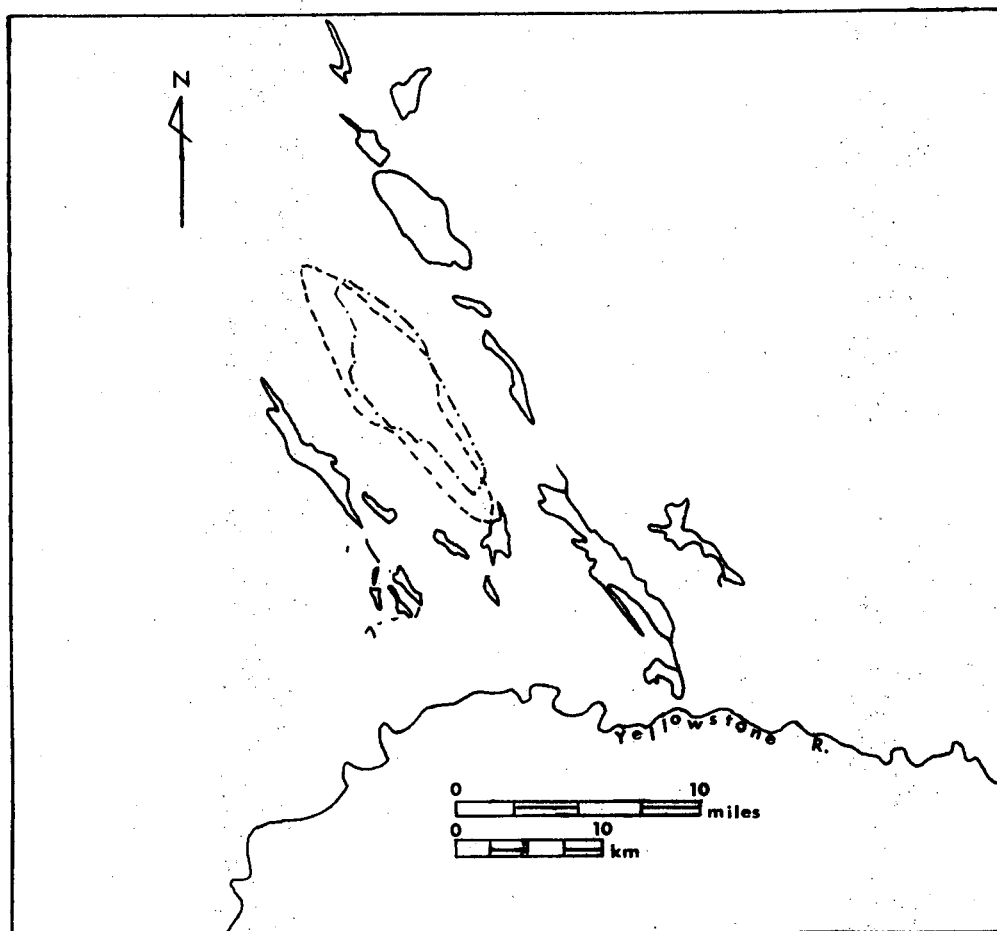



Figure 7. Clay pans and sandstone-shale contacts on the Ingomar anticline.  highly reflective clay pans from ERTS imagery, ---- ERTS tonal contact, - - - ground truth contact, top of Judith River Formation (sandstone), base of Bearpaw shale.

## PROGRAM FOR NEXT REPORTING INTERVAL

Emphasis will be placed on more detailed analysis, utilizing 18" ERTS prints and concentrating on our test sites, in which U-2 photography will be used to bridge the gap between compiled ground truth maps and satellite imagery. Test site mosaics will be laid from 9" metric camera prints and used for tectonic annotation. Rock recognition investigations will be done from the ground up, using multispectral Vinten camera pictures for comparison with space imagery, both for individual spectral bands and for optical color enhancements; metric camera color-infrared pictures will be studied for clues to the distribution and influence of vegetation. The eastern Montana site (354F), for which investigations have been deferred, will be analyzed in detail.

In addition to carrying out detailed studies, we will prepare for statewide aspects of the investigation by constructing tone-matched mosaics for the entire state at a scale of 1:1,000,000 and for the western Montana area at a scale of 1:500,000.

## CONCLUSIONS

Evaluation of data analysis methods indicates that Band 7 is best for most of our imagery interpretation purposes, and that Band 5 provides useful additional information. We have found that 18" prints are better than 9" prints for annotation purposes because of the detail which can be seen and drawn. Negative prints are useful in affording a different viewpoint and often aid in the interpretation of drainage and landforms. The Zoom Transfer Scope is quick and convenient for transfer of annotations to base maps and for direct comparison with ground truth maps; 9" diapositives are the best medium for direct interpretation on this instrument. Vinten and metric camera U-2 test site photographs are exceptionally useful for relating ground truth maps to ERTS imagery. The metric camera color-infrared pictures are especially helpful in revealing geologic and vegetative detail; derived black and white prints provide a medium for annotation.

Pilot studies indicate that ERTS imagery is very useful for tectonic mapping purposes, both for lineament mapping and for delineation of folds, domes, and dip slopes. More than 100 lineaments represent most of the major faults of western Montana (except for overthrusts) and a large number of suspected faults to be checked further. Northeast-trending lineaments are prominent south of a line connecting Missoula and Great Falls. One of the mapped lineaments, which corresponds to a known fault in the Libby Dam area, was the location of two earthquake epicenters in August of 1972. Under ideal conditions laccolithic domes several miles in diameter may be clearly delineated and plunging folds as narrow as one mile across may be outlined.

ERTS imagery was successfully used to outline areas of mountain glaciation, intermontane basins, the Adel Mountain volcanic field, and an area of granitic rocks in the Pioneer Range, although in the last case identification of the rock type from imagery was equivocal. Where tilted and eroded, undivided Paleozoic strata may be identified and separated from undifferentiated Mesozoic formations. Although photogeologic contacts can sometimes be drawn, in general, positive identification of gross rock types from imagery alone is very limited at this stage of the study.

Sufficient work has been done to suggest that ERTS imagery will be very helpful in regional tectonic analysis and for speeding compilation of a needed tectonic map of Montana at a scale as large as 1/500,000. Several examples from our studies suggest that, when calibrated from ground truth, ERTS imagery will provide corrected contact locations useful in revising the state geologic map.

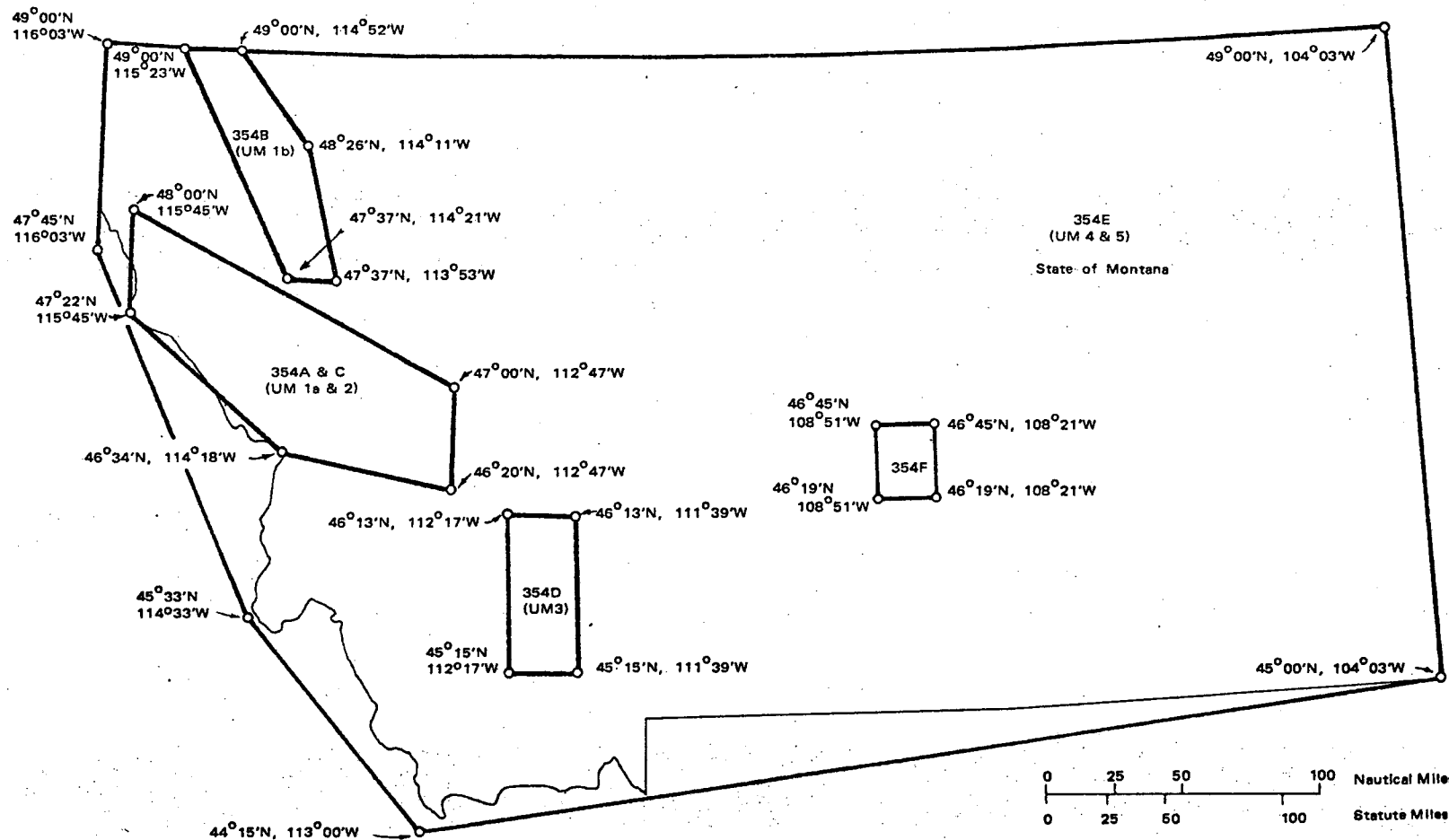
#### RECOMMENDATIONS

The dark-toned prints supplied by the NDPF for late fall can be studied by us only with back-lighting and are barely usable for overlay annotation. We, therefore, recommend that NASA consider supplying prints and dispositives normalized to give the average tone of summer prints.

Our darkroom has an Omega enlarger capable of making fine prints from negatives of conventional tone, but it is not suitable for satisfactory printing of 9" and especially 18" enlargements from the very dark NDPF-supplied negatives; exposure times are impractically long. Preparation by us of lighter tone copy negatives is expensive and degrades the quality of final prints. We, therefore, recommend that NASA consider providing optional negatives of lighter tone, at least for Bands 5 and 7.

#### REFERENCES

- Berg, R. B., 1970, Bentonite deposits in the Ingomar-Vananda area, Treasure and Rosebud Counties, Montana: Montana Bureau of Mines and Geology Spec. Pub. 51.
- Burfeind, W. J., 1967, A gravity investigation of the Tobacco Root Mountains, Jefferson Basin, Boulder batholith, and adjacent areas of southwestern Montana: unpubl. Ph.D. thesis, Dept. of Geology, Indiana Univ.
- LaPoint, D. J., 1971, Geology and geophysics of the southwestern Flathead Lake region, Montana: unpubl. Master's thesis, Dept. of Geology, Univ. of Montana.
- Ross, C. P., Andrews, D. A. and Witkind, I. J., 1955, Geologic map of Montana: U.S. Geological Survey.



University of Montana ERTS-A Test Sites. Identification is by NASA site numbers (354A) and University of Montana proposal numbers (UM 1a).

APPENDIX B. EQUIPMENT AND U-2 PHOTOGRAPHY STATUS

Items Received During December 1972 - January 1973

	Date Delivered
I. New Government Furnished Equipment*	
Drawing attachment & hood for binocular microscope	Dec. 21
B & L zoom stereoscope	Jan. 29
II. New Departmental Equipment	
B & L Zoom Transfer Scope	Jan. 12
III. New U-2 Photographic Products	
Metric camera color-IR duplicate transparencies for Flight 72-125 (contact panchromatic negatives included)	Dec. 4
Vinten camera 2nd generation negatives for Flight 72-125	Dec. 11
Metric camera color-IR duplicate transparencies for Flight 72-138 (contact panchromatic negatives included)	Dec. 21

\* Still not received are the 70mm cassettes needed for use with U-2 diapositives in the color additive viewer. These are on backorder due to manufacturing problems.